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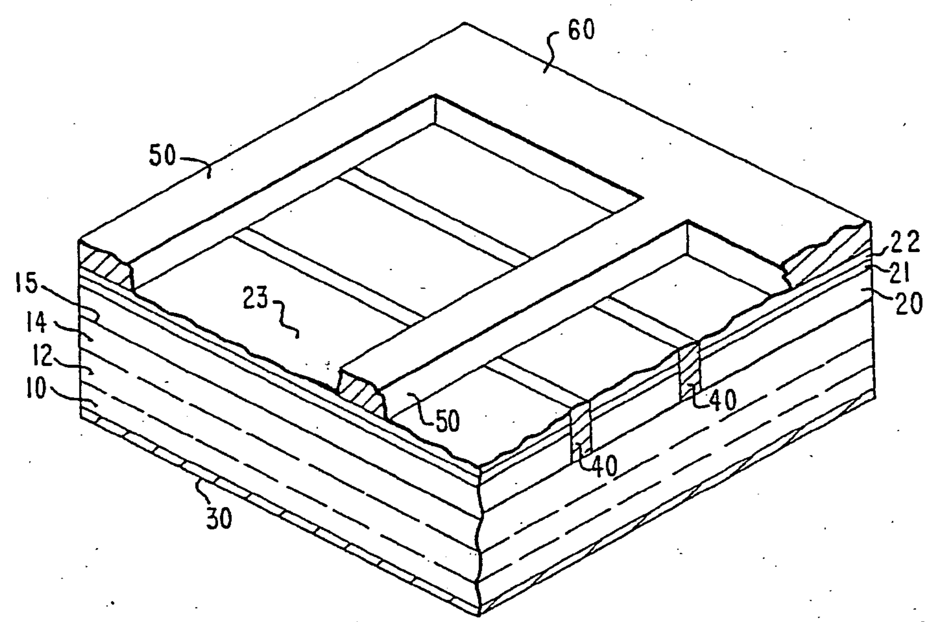

(57) Abstract

A gallium arsenide solar cell (6) having an aluminum gallium arsenide window layer (20) in which fine metallic contact lines (40) extend through the aluminum gallium arsenide window (20) to electrically contact the emitter layer (14), and a plurality of metallic grid lines (50) disposed on the window layer (23) cross the contact lines, thereby making electrical contact to the metallic contact lines (40). A flat metallic strip (60) extending along one of the edges of the solar cell electrically couples the grid lines (50) to one another. Consequently, two separate metals can be used, one with good ohmic contact properties for the metallic contact lines (40) and another with good adhesion and current conducting properties for the metallic grid lines (50). Additionally, the metallic contact lines (46) can be made very narrow to reduce the contact area to the emitter (14) thereby reducing the recombination current in the emitter.

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SOLAR CELL HAVING IMPROVED FRONT SURFACE METALLIZATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates in general to solar cells, and more particularly, to solar cells having improved front surface metallization.

2. Description of Related Art

Conventional solar cells consist of a semiconductor body having a P-type conductivity layer, an N-type conductivity layer, an N-P or P-N semiconductor junction between these layers, a front light-receiving major surface and a back major surface. The layer adjacent the front surface is called the emitter, and the layer adjacent the back surface is called the buffer. When light energy impinges on the front light-receiving surface of the cell, electrons and corresponding holes are created in both the emitter and buffer. For the most part, because of the presence of the semiconductor junction, electrons will be directed toward one major surface of the cell and holes toward the other major surface, resulting in a photocurrent density. In a typical P-N gallium arsenide semiconductor junction solar cell, holes move to the front light receiving surface of the cell and electrons toward the back surface. Electrical contacts are attached to the front and back surfaces of the gallium arsenide semiconductor body

to collect the charge carriers. The electrons are collected by the back electrical contact and holes by the front electrical contact. The object is to collect as many electrons and holes as possible before they recombine, to attain the highest photo-current density possible.

A portion of the carriers directed toward the front surface, however, recombine under the front contact and thus do not contribute to the photo-current density. This is known in the art as the front surface recombination velocity. The front electrical contact of a gallium arsenide solar cell is one area where cell improvement has been sought by industry.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide a solar cell in which front surface emitter recombination current is minimized.

It is a further object of this invention to provide a solar cell with improved open circuit voltage and efficiency.

It is still a further object of this invention to provide a solar cell which can be reproducably manufactured with high yield.

In accordance with the foregoing objects, a solar cell according to the present invention includes a semiconductor body having at least two adjacent impurity doped semiconductor layers of opposite conductivity type forming the base and emitter layers of the solar cell respectively, with a semiconductor junction therebetween. The base and emitter layers have back and front major essentially parallel surfaces, respectively. A layer of aluminum gallium arsenide is disposed over the emitter layer front major surface and has an exposed major surface. The aluminum gallium

arsenide layer has a plurality of transverse grooves therein that extend vertically through this layer to the emitter layer front major surface. The grooves contain metal contact lines that electrically contact the emitter layer for charge carrier collection. A plurality of current collecting metallic grid lines located on the exposed front major surface cross the metallic contact lines making electrical contact to these contact lines. A flat metal strip also located on the aluminum gallium arsenide exposed major surface electrially couples the current collecting metallic grid lines to one another and provides a region for welding interconnection to other solar cells.

Other and further objects, advantages, and characteristic features of the present invention will become apparent from the following detailed description of preferred embodiment of the invention when taken in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1(a) is a plan view of a portion of a solar cell according to the principles of the invention;

FIG. 1(b) is a cross-sectional view taken along line b-b of FIG. 1(a);

FIG. 2 is a perspective view partly in section of a portion of a solar cell shown in FIG. 1a;

FIG. 3 is a plan view of a portion of a solar cell in accordance with another embodiment of the invention;

FIG. 4 is a plan view of a solar cell in accordance with the invention.

FIGS. 5(a)-(g) are respective cross-sectional views (FIG.5(g) also being in perspective) of a preferred method of fabricating a solar cell according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now, with greater particularity, to FIGS. 1a, 1b, and 2, a solar cell 6 is shown having a semiconductor body 7 with front and back major parallel surfaces 8 and 9. The semiconductor body includes a substrate layer 10 which may be gallium arsenide, although germanium or silicon may be used instead. The substrate layer 10 may be impurity doped to an N+ conductivity, for example. A buffer layer 12 overlies substrate 10 and is typically gallium arsenide which may be impurity doped to an N type conductivity, for example. If the substrate layer 10 is made of silicon semiconductor material, a layer of germanium is disposed between the substrate 10 and the gallium arsenide buffer 12 to lattice match the silicon semiconductor material to the gallium arsenide semiconductor material. An emitter layer 14 of gallium arsenide semiconductor material overlies the buffer layer 12 and may be of a P-type conductivity. An N-P junction 13 lies between the emitter layer 14 and the buffer layer 12. Overlying the emitter layer 14 is an aluminum gallium arsenide window layer 20 which is of the same conductivity type as the emitter layer 14, i.e., P-type conductivity.

Although an N-P semiconductor body is illustrated in FIG. 1b, a P-N semiconductor body may also be used where the substrate 10 is of P+ conductivity, the buffer layer 12 is of P conductivity, the emitter layer 14 is of N conductivity, and the window layer 20 is of N conductivity.

Two antireflection coatings 21 and 22 overlie the front major surface 8 of the aluminum gallium arsenide window layer 20. The top antireflection coating 22 has an exposed major surface 23, and may be aluminum oxide,

and the bottom antireflection coating 21 may be titanium dioxide, for example. While two layers are typically used, fewer or more layers may be used. If a single layer is employed, it may be either silicon monoxide or tantalum oxide, for example.

A back contact 30 is located on the back major surface 9 of the semiconductor body 7. The back contact may cover the entire back surface of the solar cell or may be gridded.

A plurality of essentially parallel metallic contact lines 40 traverse the extent of the exposed major surface 23 of the cell. The metallic contact lines 40 typically have a rectangular cross-section and extend through the two anti-reflection coatings 21 and 22, and the aluminum gallium arsenide layer 20, to make contact to front major surface 15 of the emitter layer 14. The metallic contact lines 40 may be about 5 to 10 microns wide, for example. Narrower contact lines provide less contact area to the emitter layers lowering the emitter recombination current under the contacts by reducing the amount of emitter material exposed to a high recombination velocity region. Alternatively, instead of the contact lines 40 of FIG. 1, a plurality of metal rectangular contact segments 41 arranged in rows and columns, may be provided, as shown in FIG. 3, which further reduce the contact area to the emitter. Adjacent metal contact lines 40 or segments 41 may be spaced about 800 microns apart.

Current collecting metallic grid lines 50 disposed on the exposed major surface 23 of the top anti-reflection coating 22 longitudinally traverse the extent of the cell 6 generally perpendicular to the metallic contact lines 40. The metallic grid lines 50 cross and make electrical contact with the metallic contact lines 40. The width of the grid lines 50 may be about 25 to 60 microns, for example, but 30 to 40 microns

provides good results. Adjacent grid lines may be spaced apart by a distance of one to two millimeters, (one-half to one millimeters for FIG. 3) for example. The optimal spacing between adjacent grid lines 50, however, varies with the width selected for the metal contact lines 40, and the width and height of grid lines 50.

A flat metal strip 60 traversingly extends across the cell and is located on the exposed major surface 23 of the top anti-reflection coating 22 near an edge of the cell 6. The strip 60 is essentially parallel to the metallic contact lines 40 and substantially perpendicualr to the current collecting metallic grid lines 50, being intersected by and in electrical contact with grid lines 50. The flat metallic strip 60 may have a rectangular surface area, or as shown in FIG. 4, may instead be in the form of a very narrow metallic strip 61 with one or more extended metallic regions 62 along the length of the strip 61. The extended regions 62 have sufficient surface area to weld to electrical interconnections from other cells.

A solar cell 6 is described above in which the contact resistance to the solar cell and the adhesion of the front electrical contacts to the solar cell can be individually optimized, and the contact area of the front surface metalization minimized. A metal alloy can be selected for the metal contact lines 40 that provides good electrical contact to the emitter layer 14, thereby lowering contact resistance and increasing efficiency. A different metal alloy can be selected for the current collecting metallic grid lines 50 and the flat metallic strip 60 that provides good adhesion to the cells' exposed major face 23, thereby maximizing the mechanical integrity of the flat metallic strip 60 and the grid lines 50. Additionally, the metallic

contact lines 40 can be made very narrow, i.e., in the range of 5 to 10 microns compared to 50 to 60 microns for typical prior art cells. Consequently, the contact area of the metallic contact lines 40 to the emitter layer 14 of the cell may be greatly reduced lowering the recombination current at the emitter front major surface, and thereby increasing voltage and efficiency. Moreover, solar cells embodying the invention may be fabricated by relatively low cost, high yield processes.

The fabrication of the semiconductor body 7 has been described in several publications in the past such as G. S. Kamath, Advanced Solar Cells for Space Applications, Proceedings of 21st IECEC 1425-26 (Aug 1986) which is incorporated herein by reference. Briefly, however, as shown in FIG. 5a, a layer of N-type conductivity gallium arsenide 12, the base, is grown on top of a N+ gallium arsenide substrate 10 using any one of many well known techniques, one of which is liquid phase epitaxy. The N-type base layer 12 typically has a concentration of about 2×10^{17} impurity atoms per cubic centimeter and a thickness of about 10 microns, while the N+ substrate layer 10 typically has a concentration of about 2×10^{18} impurity atoms per cubic centimeter and a thickness of 250 microns.

In the next processing step shown in FIG. 5b, an aluminum gallium arsenide layer 20 is grown on top of the N layer 12 by liquid phase epitaxy, metal organic chemical vapor deposition, molecular beam epitaxy, for example. The aluminum gallium arsenide is doped with a P-type dopant which may be beryllium of a typical concentration of 2×10^{18} atoms per cubic centimeter,

for example. Upon deposition of the aluminum gallium arsenide layer 20, beryllium atoms from this layer diffuse into the N layer 12 thereby doping a thin emitter layer 14 adjacent the aluminum gallium arsenide layer 20 to P-type conductivity. The aluminum gallium arsenide layer 20 typically contains about 2 x 10^{18} impurity atoms and is grown to a thickness of about 0.03.-0.4 microns.

After the semiconductor body 7 has been fabricated, two anti-reflection coatings 21 and 22 typically of aluminum oxide and titanium oxide, respectively, may be deposited on the aluminum gallium arsenide layer 20, by any technique known in the art, shown in FIG. 5c. However, additional or fewer layers of antireflection coatings may be employed. Reference may be made to F. Bunshah et al, Deposition Technology for Films and Coatings (Noyes Publ. 1982) which is incorporated herein by reference.

Thereafter, as shown in FIG. 5d, the back surface metallization 30 is applied. A metal alloy, such as gold, germanium, and nickel, for example, is electron beam evaporated or otherwise deposited over the back major surface 9, and thereafter sintered to form good ohmic contact to the semiconductor body 7. The back surface metallization may precede the deposition of the anti-reflection coatings without affecting the properties of the cell.

In the next step, the metal contact lines 40 are fabricated onto the solar cell semiconductor body. The exposed major surface 23 of layer 22 is provided with a patterned layer of photoresist (not shown), and the exposed portions are etched vertically through the two antireflection coatings 21 and 22 and the aluminum gallium arsenide window layer 20 to the emitter layer 14 front major surface 15, forming fine grooves 42, as

shown in FIG. 5e. Thereafter a metal alloy, such as gold and zinc, for example, is sputtered over the photoresist and into the fine grooves 42, and then silver is evaporated thereon using electron vaccum deposition. Alternatively, the metallic contact lines 40 may be deposited on the exposed major surface 23 using ion plating, evaporation from a resistive source, or electroplating. The remaining photoresist is thereafter lifted off along with the metal on the photoresist using organic solvents leaving behind the fine metallic contact lines 40, as shown in FIG 5f.

After the metallic contact lines 40 have been deposited, the metallic grid lines 50 and the flat metallic strip 60 are fabricated onto the cell, as shown by FIG. 5g. Using mechanical foil mask processing, a foil mask, with openings for the grid lines and flat strip is placed on the exposed major surface 23 of the top anti-reflection coating 22, and metal is evaporated onto the surface. The metal is thereafter sintered to provide good adhesion to the top anti-reflection coated exposed major surface 23. A metal alloy such as titanium, gold, zinc, and silver may be used, for example, which provides good adhesion.

It will be appreciated that while the embodiment of the solar cell structure illustrated herein employs an P-N semiconductor body 7, the principles of the invention are also applicable to N-P type cells.

Thus, although the present invention has been shown and described with the reference to particular embodiments, nevertheless various changes and modifications obvious to one skilled in the art are deemed to be within the spirit, scope, and comtemplation of the invention as set forth in the appended claims.

CLAIMS

What is Claimed is:

1. A solar cell comprising:

a body of semiconductor material having a first layer of a first conductivity type and a second layer of a second conductivity type opposite to said first conductivity type disposed adjacent to said first layer, said first and second layers having back and front major essentially parallel surfaces, respectively, and a semiconductor junction therebetween essentially parallel to said front and back surfaces;

a layer of aluminum gallium arsenide disposed on said front major surface and having an exposed front surface and a plurality of grooves therein extending vertically therethrough to said second layer;

a plurality of metallic contact lines in said grooves making electrical contact to said second layer;

a plurality of metallic grid lines on said aluminum gallium arsenide exposed front surface crossing said metallic contact lines and electrically contacting said metallic contact lines; and

a flat metallic strip disposed on said aluminum gallium arsenide layer exposed front surface electrically coupling said conductive bars to one another said flat metallic strip having sufficient surface area to weld interconnection from other solar cells.

2. A solar cell as defined in Claim 1 wherein said semiconductor body is made of gallium arsenide, said first layer is of P conductivity type, said second layer is of N conductivity type, and said aluminum gallium arsenide layer is of N conductivity type.

3. A solar cell as defined in Claim 1 wherein said first layer is of P+ conductivity, said second layer is of P conductivity, and said third layer and said aluminum gallium arsenide layer is of N conductivity.

4. A solar cell as defined in Claim 1 wherein said metallic contact lines are essentially parallel to one another.

5. A solar cell as defined in Claim 4 wherein said metallic grid lines are essentially parallel to one another and essentially perpendicular to said metallic contact lines.

6. A solar cell as defined in Claim 1 wherein said metallic contact lines are divided into a plurality of metallic rectangular contact segments arranged in rows and columns.

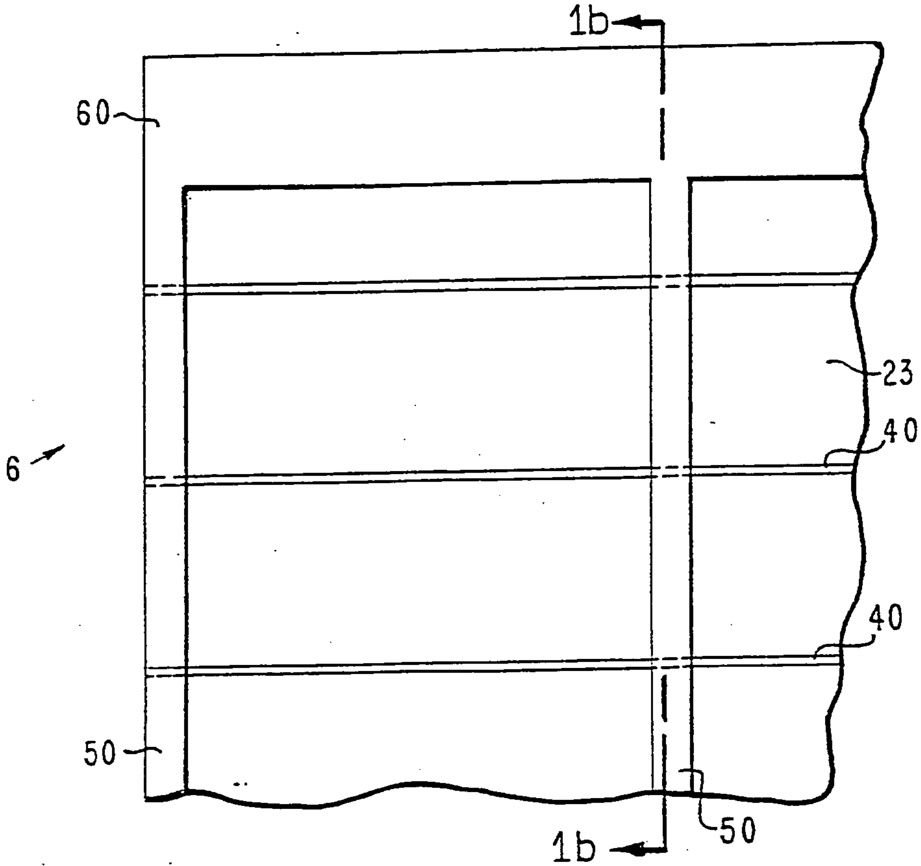
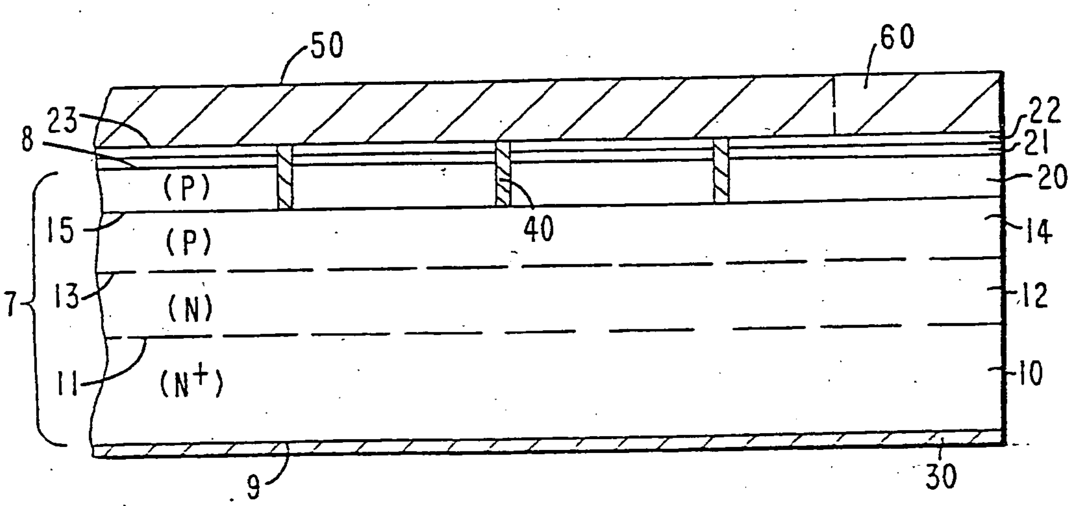

1b
60
6
23
40
40
50
50
1b

Fig.1a.


50
60
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8
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21
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7
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12
11
(N+)
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9
30

Fig.1b.

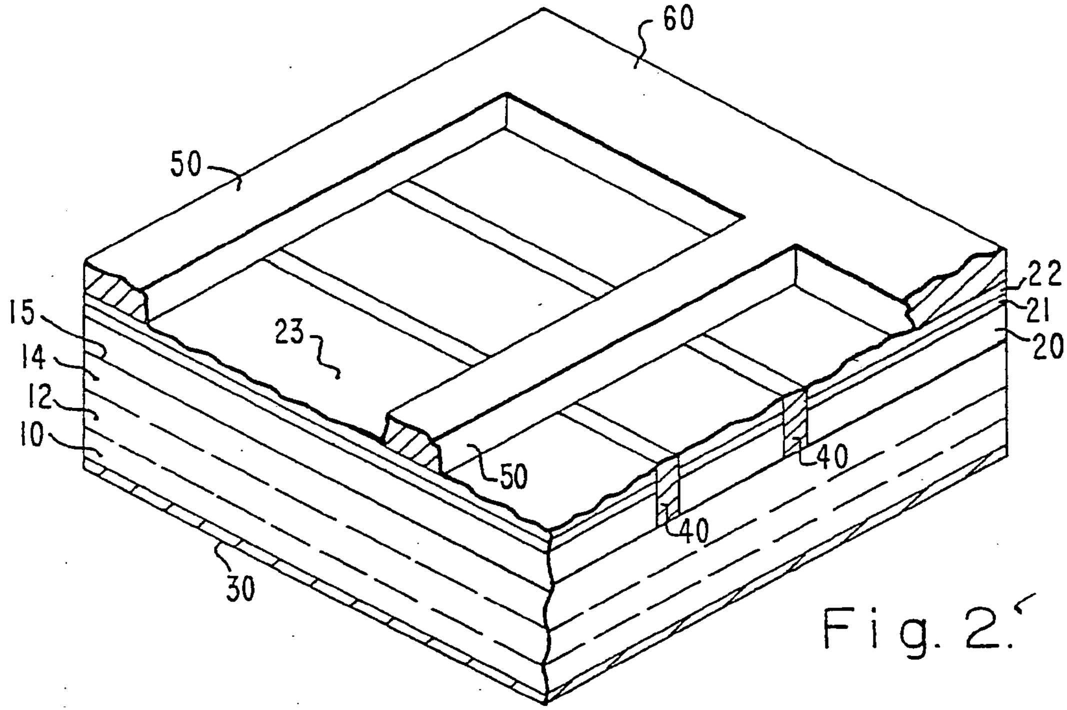


Fig. 2.

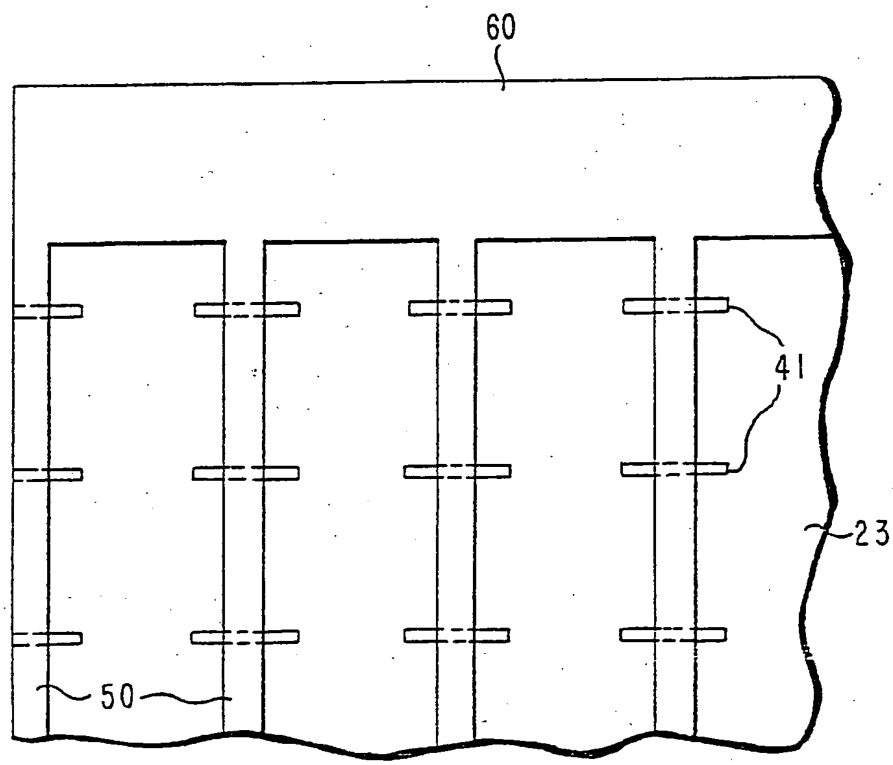


Fig. 3.

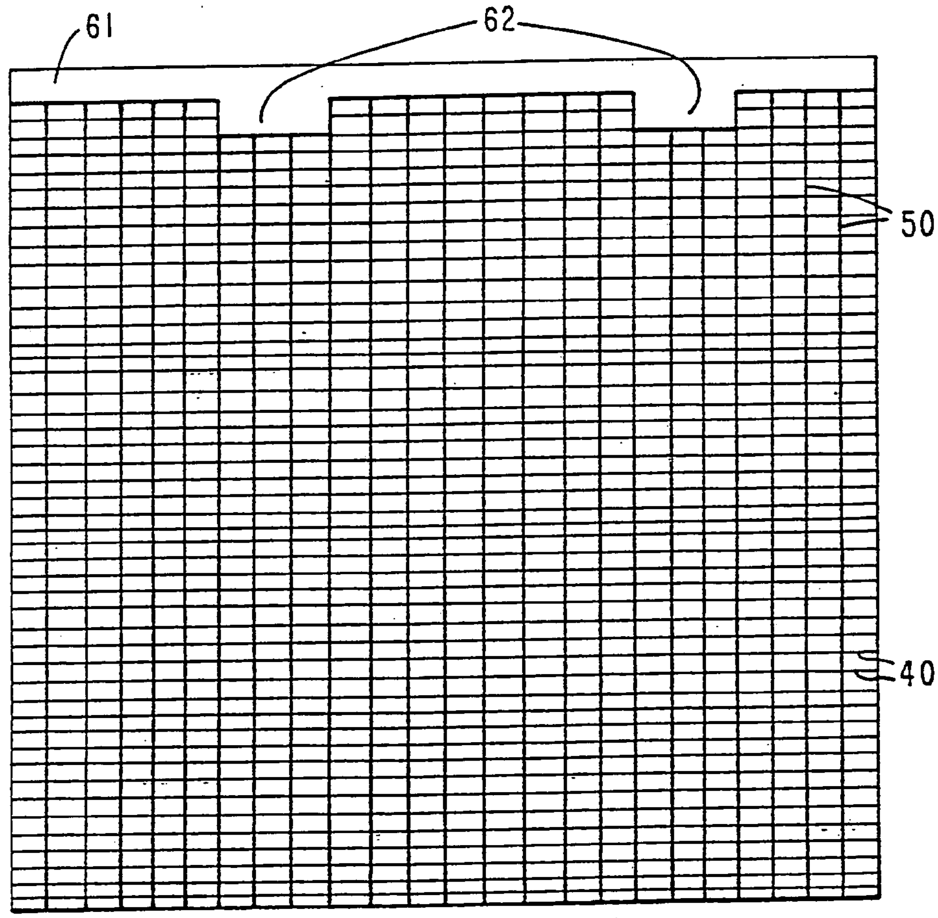
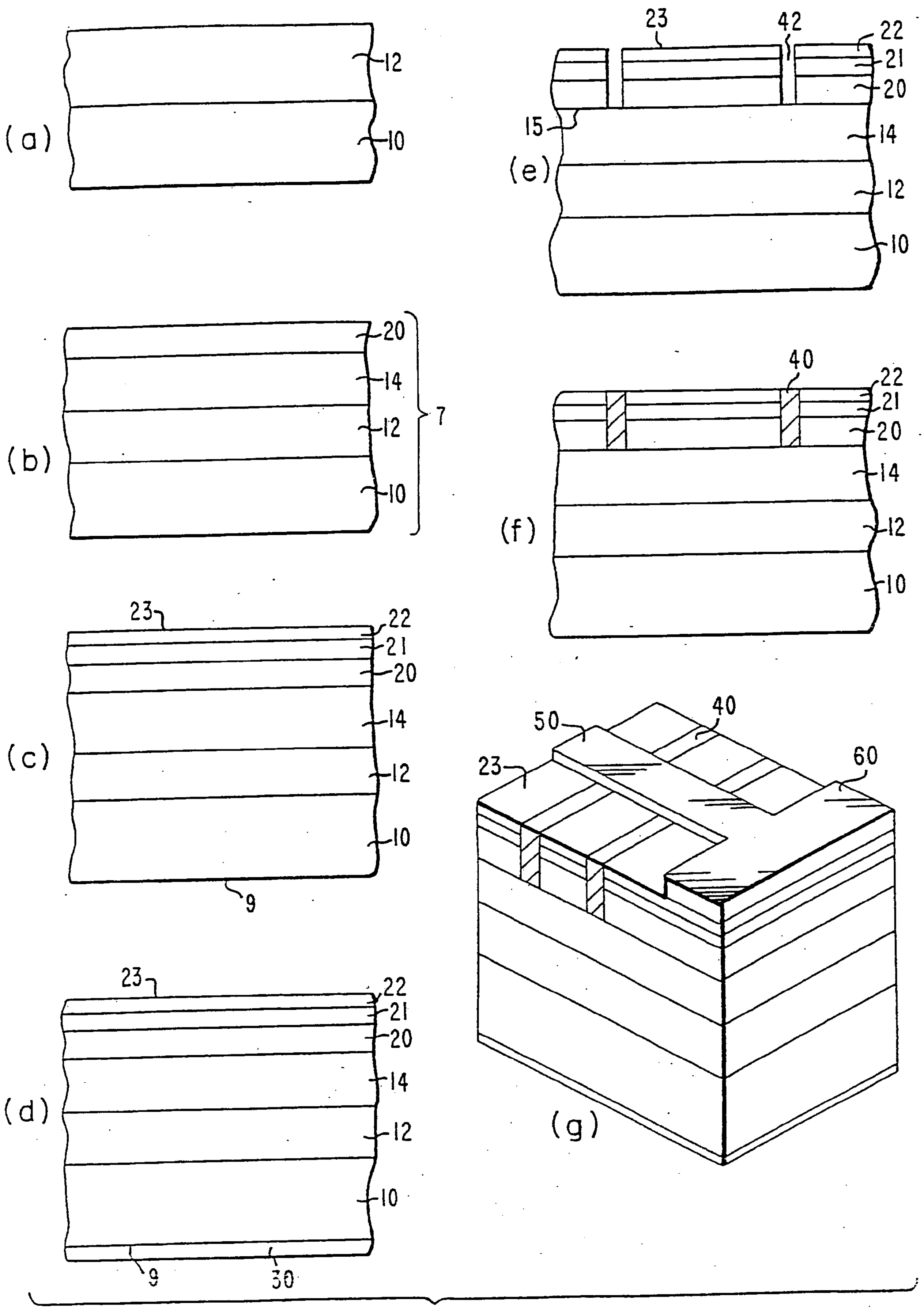


Fig. 4.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(c)
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(g)
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23
60

Fig. 5.